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# Simulated SAM A-scans on multilayer MEMS components

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## 1. Introduction

SAM has been used for several years as a microelectronics failure analysis tool though often with poor understanding of the A-scan and C-scan pictures. This is especially the case when the components consist of layers very close to each other and where phase inversions take place.

Most often MEMS contain stacks of many very thin layers. The motivation for this work has therefore been to gain better understanding of SAM A-scans on MEMS multilayer structures by simulation.

## 2. Results

All calculations have been made in an excel spreadsheet. SAM measurements were made on KSI Winsam 200 equipment.

### 2.1 Spreadsheet calculations

For given sets of reflections we calculate for each first the number  $N$  of possible reflection orders. The calculations are based on maximum 4 or 9 impedance transitions with up to 8 or 2 reflections back towards the transducer respectively (Fig. 1). Then the received amplitudes with polarity according to (1) together with the corresponding delay times are calculated.

$$A = A_0 \cdot N \cdot T_{total} \cdot R_{total} \quad (1)$$

$T_{total}$  and  $R_{total}$  are the products of all involved transmission and reflection coefficients. Due to limited available data the sound attenuation in each layer is not yet included in the calculations, however, the program is prepared for this. The spreadsheet input values are the materials acoustic impedances, the speed of sound in the materials, and the layer thicknesses.

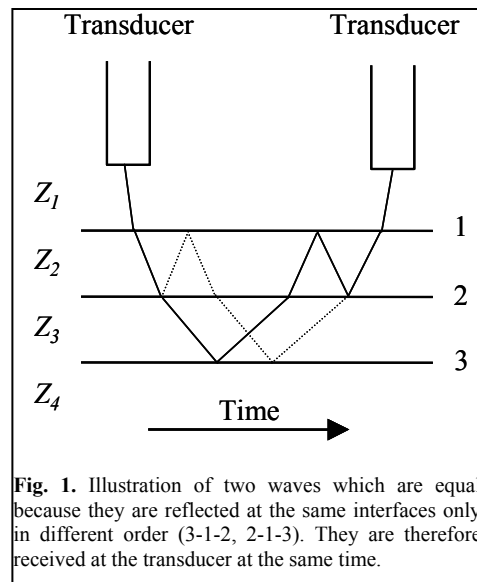
### 2.2 A-scans on fusion bonded wafers

Bonded silicon wafers with test cavities for an absolute pressure sensor have been investigated with SAM. The cavities are used to test the leakage through the bond interface into the cavity [1]. Over the cavities and down the layers are Si (350  $\mu\text{m}$ ) / cavity (2  $\mu\text{m}$ ) / Si (500  $\mu\text{m}$ ) / SiN (0.1  $\mu\text{m}$ ).

Simulations show that in order to get a scan of the interface with a minimum of overlapping waves out of phase the bonded wafers should be inspected from the Si side (Fig. 2). Then all the reflected waves have the same sign and are well separated because the time between them is 83 ns. Though, by comparing the real scan from the Si side (Fig. 3) with the simulations it is evident that this looks more like the one expected when scanning from the SiN side (Figs. 2 and 3).

## 3. Discussion

Spectra much like the one from the SiN side are achieved no matter the thin layer material and position at the exterior or next to the cavities and channels. Therefore we suggest that the thin boron diffused bond layer is acoustically different from bulk silicon, which was not expected from the start. This is supported by



**Fig. 1.** Illustration of two waves which are equal because they are reflected at the same interfaces only in different order (3-1-2, 2-1-3). They are therefore received at the transducer at the same time.

the observation that stresses built-up in such layers, which might change the longitudinal acoustic impedance of silicon significantly. I.e. we have the layers: Si (350  $\mu\text{m}$ ) / approx. 2  $\mu\text{m}$  B diffused Si / cavity (2  $\mu\text{m}$ ) / Si (500  $\mu\text{m}$ ) / SiN (0.1  $\mu\text{m}$ ).

Apart from the time position differences due to differences in Si thickness before the cavity, the real scan from the Si side resembles the A-scan simulation of inspection from the SiN side quite well because waves of opposite amplitude sign seem to overlap more or less. Note that only two signals from the interface are clearly seen, i.e. the first and second time reflections from cavities / channels at around 83 ns, 166 ns and 118 ns, 237 ns in the real scan from the Si side (Figs. 2 and 3) and in the simulation of inspection from the SiN side (Fig. 2) respectively. The rest of the signals essentially die because waves with opposite phase are added. Already from the second time echoes this begins to happen e.g. by addition of 3-1-3-.. and 3-2-3-.. reflections in the case of inspection from the SiN side. Even though the second time reflection from the cavity has passed two times through the silicon material, the amplitude is high because of the high  $N$  value.

#### 4. Conclusion

A calculation method and spreadsheet program for simulation of SAM A-scans on multilayer structures have been developed. The useful information, which the simulations provide, has been demonstrated on fusion bonded wafers containing MEMS pressure sensor test cavities in the interface. Unexpectedly it was found that an extra layer on the wafer without etched cavities / channels has influence on the A-scans. Presumably this layer is a B diffused bond layer.

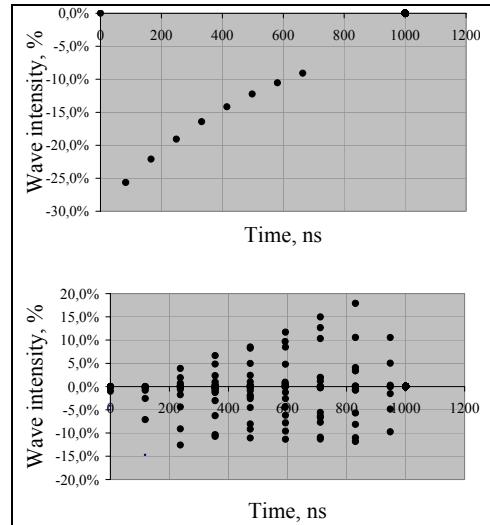
Generally, it has been shown that structure variations in samples can be simulated and therefore analysed better. Failures or variations in MEMS structures can be analysed by investigating the effect of introducing them in the A-scan simulations and comparing them with real A-scans.

#### 5. Acknowledgement

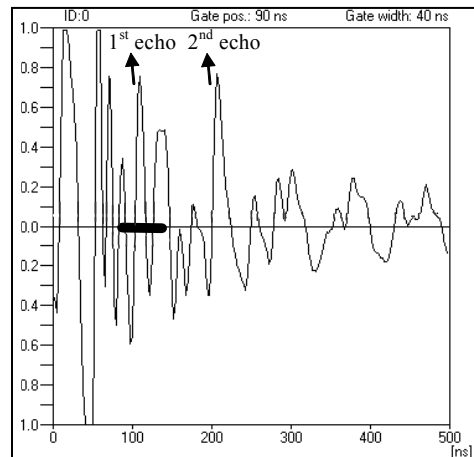
This work has been part of the collaboration on development of microsystems (SUM) project between two Danish institutes DELTA, the Microelectronics Centre (MIC), and four Danish companies Capres A/S, SonionMEMS A/S, Danfoss A/S and Grundfos A/S. The project is financially supported by the Danish Agency for Trade and Industry.

#### 6. References

- [1] K. Birkelund, M. Sørensen, S. Chiriaeve, P. Gravesen and P. B. Rasmussen, High pressure sensor based on fusion bonding, abstract 1482 in: Proc. of the 6<sup>th</sup>. Int. Symp. on Semiconductor Wafer Bonding: Science, Technology and Applications, The Electrochem. Soc., San Francisco (2001).



**Fig. 2.** Simulated amplitudes of A-scans on bonded wafers with cavities. Each dot shows amplitude and time for a back reflected wave. Top: Inspection from Si side. Bottom: Inspection from SiN side. Note that in this case many waves are received at the transducer at the same times.



**Fig. 3.** 110 MHz SAM A-scan on Si (350  $\mu\text{m}$ ) / approx. 2  $\mu\text{m}$  B diffused Si / cavity (2  $\mu\text{m}$ ) / Si (500  $\mu\text{m}$ ) / SiN (0.1  $\mu\text{m}$ ) from Si side. Note that surface trigger is in the front of the wave reflected at the top surface. First and second reverberations from the cavity starting at 83 ns and 166 ns respectively are observed (arrows). The gate indicated by a black bar is a filter which is here open for the first signal.